ON

THE FOOD OF MAN

IN RELATION TO

HIS USEFUL WORK.

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ON THE FOOD OF MAN IN RELATION TO HIS USEFUL WORK.

1. The great generalization of Liebig, that food contains two chief classes of organic ingredients, one class consisting of nitrogenous substances, which give the plastic materials for the formation of tissues, while the other class contains the amylaceous and saccharine bodies destined to support the heat of the animal body, has met with general acceptance, notwithstanding the objections entertained by some physiologists to the general terms of the division. They state that the nitrogenous aliments may also support animal heat, as well as fulfil their special function of forming the tissues. But the distinguished author of the classification admitted this fact in his first work,[1] when he pointed out that the carnivora must waste their tissues in the support of animal heat. The recent experiments of Bischof and Voit,[2] and of Pettenkofer and Voit,[3] in feeding animals on flesh from which all fat had been removed, completely prove that nitrogenous substances can act as heat-givers as well as flesh-formers. But the converse of the classification is not true, for we have not the

[1] Animal Chemistry, p. 120.
[2] Die Gesetze der Ernährung des Fleischfressers, p. 56, *et seq.*
[3] Ann. der Ch. und Phar. Supp. Bd., 1863, p. 361, *et seq.*

slightest evidence to show that alimentary bodies free from nitrogen can build up any organ of the body. It is known that a small quantity of fat is always present in healthy tissue, but it may be wholly removed by ether without injury to the organic structure. The same experiments which proved that flesh-formers might when necessary act vicariously as heat-givers, have also proved that the nutrition of carnivora may be effected without the supply of fat or any other non-nitrogenous body.

2. The chief object of this lecture is to examine the function of nitrogenous ingredients of food, as a magazine of force for the production of dynamical effects in the animal. The consideration of the animal body as a machine, and of the food in the light of fuel supplied to it, has already engaged the attention of philosophers. Rumford,[1] Joule,[2] Mayer,[3] Helmholtz,[4] Dumas,[5] Hirn,[6] Fick,[7] and Carpenter,[8] have published their views on this important subject, but all of them, so far as I know their writings, have looked upon food in its aggregate, applying their calculations to the total carbon and hydrogen contained in it, without discussing the influence exerted by its separate constituents in the production of force.

3. The Rev. Dr. Haughton of Dublin has been an exception in this respect. He has endeavoured to find in the urine the representative of the mental, vital, and

[1] Rumford's Essays, vol. ii. p. 488.
[2] Joule and Scoresby, Phil. Mag. 1846, p. 454.
[3] Mayer, Die organische Bewegung in ihrem Zusammenhang mit dem Stoffwechsel, 1845.
[4] Helmholtz, Lectures at Royal Institution (Lect. vi.), 1864.
[5] Dumas, as quoted by Matteucci, Phy. Phen. of Living Beings, p. 325.
[6] Hirn, Théorie Mécanique de la Chaleur, p. 34.
[7] Fick's Physiologie des Menschen, p. 291.
[8] Carpenter's Jour. of Science, 1864, p. 266.

mechanical work of the human body, and gives the following equations:[1]—

Opus Mechanicum, or 150 lbs. raised one mile,	= 136·5	grains of urea.
Opus Mentale, or five hours of study, . .	= 217·0	" "
Opus Vitale, . .	= 297·0	" "

He then draws the conclusion that in manual or routine bodily labour, men are sufficiently well fed when they receive as much food as will discharge 400 grains of urea daily (the product of 2·8 oz. of flesh-formers), of which 300 grains are spent in vital work, and 100 grains (the product of less than three-fourths of an ounce of flesh-formers) in mechanical work. But when the work is of a higher order, Haughton states that a better quality of food must be supplied, sufficient to allow a discharge of 533 grains of urea daily, of which 300 grains are spent as before in vital work, and 233 grains in the mental and mechanical work necessary to keep the body in health.

4. If we are to understand these numbers of Haughton as being true exponents of the quantity of tissues necessary to be transformed for the production of force, the latter can readily be calculated and compared with that necessary to effect the work. Urea can only be an exponent of work, inasmuch as it shows us the quantity of tissue which has become oxidised in its production, and thus enables us to express the amount of energy stored up in that tissue, and in the oxygen which transformed it. Now, as 136·5 grains of urea are said to be equal to 150 lbs. weight raised to the height of one mile, we ought to find at least this amount of potential energy in

[1] Haughton on Healthy Urine of Man, p. 32.

the 405 grains of tissue from which the urea must have been derived, and in the oxygen required to convert it into this diamine. After deducting the hydrogen which may be supposed to have already met with oxygen in the tissues, we have available for transformation—

190·6	grains of	carbon.
12·5	do.	hydrogen.
5·1	do.	sulphur.

These numbers, by the usual formula, would give 498·8 lbs. of water raised 1° Fah., and this, converted into its mechanical equivalent by the co-efficient 772, represents 385,073 lbs. raised to the height of one foot. This then represents the total potential energy, while the actual work realized by the man is more than double this amount, or is 792,000 foot-pounds. It is clear, then, that Haughton cannot have meant the equations given by him in the mathematical sense of equality, but only in the general sense of representation. In fact, in a further paper[1] he points out that the combustion of the carbon and hydrogen of the proteine compounds can only account for 54 per cent. (misprinted 34 per cent.) of the work ascribed to the urea. Hence we are obliged to class Haughton with the other writers, who consider that the transformation of the nitrogenous tissues is insufficient to account for the dynamical movements of the body.

5. In discussing this subject anew, I divide the work performed in the body as follows :—

1. Mental work.
2. Calorific work.
3. Internal dynamical work.
4. External do. do.
5. Digestive or assimilative work.

[1] Haughton on Diabetes Mellitus, p. 30.

With the two first divisions we have little to do in the present lecture; with the three last divisions we shall be fully occupied.

6. It will be convenient to proceed in the following order:—

Division I.

A. To ascertain the amount of food necessary for mere subsistence without exercise.

B. To determine the amount of food required for complete health, with a moderate exercise of from five to seven miles daily.

C. To fix the amount of food suited for active work, such as is represented by a man walking twenty miles daily continuously.

D. To find the amount of food consumed by labourers with very arduous occupations, such as navvies engaged on railways.

Having ascertained these preliminary facts, which are altogether independent of theory, we shall then be in a position to proceed to

Division II.

A. To discuss whether there be sufficient potential energy in the nitrogenous tissues, or of the food representing them, and in the oxygen required for their transformation, to account for the dynamical actions within or without the body.

B. To consider whether the fatty and amylaceous or saccharine ingredients of food are employed in this mechanical work.

Having discussed these points, we should then be in a position to proceed to

Division III.

A. To inquire whether the secretions of urea and uric acid *per vesicam* are sufficient representatives of labour performed.

B. To consider what is represented by the nitrogenous materials secreted *per anum*.

Division I.

Food required under different Conditions of Work.

7. In determining the amount of food required for mere subsistence, we ascertain, at least approximatively, that necessary for internal dynamical work. By that we mean such work as is carried on within the man independently of the will, and in the direction of which he is an unconscious agent. The heart beats, the blood circulates, the lungs play, the diaphragm acts, the intestines exert their peristaltic motion, by an inner directive movement. In the exercise of these motions a certain amount of force is expended, but it is ultimately converted into heat, and aids the *opus calorificum*, which is chiefly produced by the combustion of the non-nitrogenous parts of food.

In looking for a purely subsisting diet, we naturally turn to the experience of hospitals having convalescent patients unable still to take exercise. The following is the dietetic value in ounces of the "common diet with bread," employed at the Infirmary in Edinburgh.[1]

[1] The ounce used in this lecture is always 437·5 grains, or 28·35 grammes, the gramme being taken at 15·43 grains.

Flesh-formers,	2·06 oz.
Fat,	0·58 „
Starch,	11·33 „
Starch equivalent of heat-givers,	12·69 „
Mineral matter,	0·35 „

In this diet the amount of carbon in the flesh-formers is 1·08 oz., and in the heat-givers 5·57, or together, 6·58 oz. This amount of carbon fairly represents that required to keep up the vital actions, for Dr. E. Smith[1] found, in his own case, that 6 oz. of carbon were exhaled by him during one day's starvation, and Ranke,[2] in a three days' trial, found 6·4 oz. every twenty-four hours. We may therefore assume that 6·5 oz. of carbon are required to support the life of an adult man without exercise. In the following Table are some recorded instances of deficient dietaries, although in some of the cases they were only defective because work was expected from the persons living upon them. They are therefore generally sufficient for mere subsistence during rest, but insufficient for the performance of labour.

An examination of the information furnished by this Table will justify the conclusion that though 2 oz. of flesh-formers, 0·5 oz. of fat, 12 oz. of starch and sugar, containing a total amount of 6½ oz. of carbon, will suffice for a man to support the internal dynamical motions and other vital necessities of his body when he is at complete rest, they are not compatible with a moderate amount of exercise; so that, even in the condition of low health without activity, 2·5 oz. of flesh-formers, 1 oz. of fat, 12 oz. of starch, and 0·5 oz. of mineral matter are necessary. This diet contains 7·44 oz. of carbon.

[1] Smith, Trans. Roy. Soc., vol. cxlix. p. 681.
[2] Ranke, Müller's Archiv. 1862, S. 342.

TABLE I.—SUBSISTENCE AND LOW DIETARIES.

DIETARIES.	Flesh-formers.	Fat.	Starch, etc.	Starch equiv.'	Carbon.
Contractors' insufficient prison diet, Bengal,[1]	2·05	0·73	17·84	19·58	9·585
Dundee Prison diet, treacle substituted for milk, 50% of prisoners lost weight,[2] . .	2·87	0·87	13·41	15·41	8·168
Needlewomen in London,[3]	1·90	1·04	10·29	12·74	6·392
"Common diet," Edinburgh Infirmary,[4] .	2·06	0·58	11·33	12·69	6·585
Average diet during cotton famine in Lancashire, 1862,[5] . . .	2·72	...	...	...	9·540
Diet of the prisoners in Libby Prison, Confederate States,[6] . .	2·41	0·98	5·62	8·01	4·546
MEAN SUBSISTENCE DIET,	2·33	0·84	11·69	13·68	7·469

8. We have now to get a mean dietetic value for the food of an adult man in active health, but without hard labour. The dietaries of soldiers during peace offer us a large experience. I have recalculated the following Table, which was published formerly by me in a less complete form,[7] taking bread as containing 37 per cent. of water.[8] The data for the calculations have been obtained from the sources quoted below.

[1] Report of twenty-four Pergunnahs, 1847.
[2] Christison, Edin. Journ. Med. Soc. May 1852.
[3] Rep. of Med. Officer of Privy Council, 1862.
[4] Diet Tables of Edinburgh Infirmary, 1865.
[5] Rep. Med. Off. Privy Council, 1863, p. 322.
[6] Report of American Sanitary Commission, 1865.
[7] Good Words, January 1865.
[8] Lawes and Gilbert, Chem. Soc. Journ. x. 54.

TABLE II.—DIETARIES OF SOLDIERS DURING PEACE.

	Weight of Solid Food.	Flesh-formers.	Fat.	Starch, Sugar, Cellulose, etc.	Starch Equivalent of Heat-givers.	Mineral Matter.	C Carbon in Flesh-formers.	C′ Carbon in Heat-givers.	Total Carbon C + C′.	Ratio of C : C′ 1 : x.	Ratio of Flesh-formers to Starch Equivalen 1 : x.
	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.
English soldiers,[1] . .	59·67	4·250	3·465	18·541	22·594	0·789	2·286	10·900	13·186	4·768	5·316
French soldiers,[2] . .	48·6	4·406	1·431	19·142	22·579	0·700	2·370	9·600	11·970	4 050	5·124
Prussian soldiers,[3] . .	55·0	3·995	1·105	19·472	22·124	0·724	2·149	9·496	11·645	4·418	5·537
Austrian soldiers,[4] . .	40·75	4·210	1·389	17·606	20·940	0·645	2·264	8·886	11·150	3·924	4·973
MEAN DIETETIC VALUE, .	**51·0**	**4·215**	**1·847**	**18·690**	**22·059**	**0·714**	**2·267**	**9·720**	**11·987**	**4·290**	**5·237**

The mean of this Table may fairly be taken as representing the value of food required to keep adult men in good health. According to the statements of surgeons[5] in the army, the rations

[1] Parke's Practical Hygiène, p. 144.
[2] Code des Officiers de Santé, 1862, p. 481.
[3] Hildesheim, Die Normal Diät, p. 60.
[4] Parkes, p. 148.
[5] Dr. Buckland of the Guards, Soc. of Arts Journ. 1863.

of our own soldiers, which do not differ widely from the mean, are not sufficient for recruits during their drills, though the sergeants fatten upon them. As the average value is also nearly the same as that of middle class diets[1] we may safely assume it to be a correct expression of the diet of men who live well and take moderate exercise, of from five to seven miles daily.

9. Before we discuss the dietetic value of food required for men engaged in labour, we must define what we understand by a full day's work. We take such work, when performed continuously throughout the year, with rest on Sundays, to be represented by a daily walk of twenty miles. The experience of postmen in rural districts shows that more than this amount of work cannot be executed without the man breaking down. As the co-efficient of traction is nearly $\frac{1}{20}$th the weight of a man's body, the work which a standard man of 150 lbs. has to perform is 792,000 foot-pounds. That this is a full estimate will be apparent from the following Table[2] of the work of a man under different conditions :—

Kind of Labour.	Amount of Work in ft. Tons.	Authority.
Pedestrians, ...	353	Haughton.
Pile-driving, ...	312	Coulomb.
" "	352	Lamande.
Turning a winch, ...	374	Coulomb.
Porters carrying goods and returning unloaded, ...	325	Coulomb.
Porters always loaded, ...	303	"
Porters carrying wood up stairs, descending unloaded, ...	381	"
Paviours at work, ...	352	Haughton.
Prisoners at Shot Drill, . . .	310	"

Mean, 340·2 Tons = 105,605 metre kilogrammes.

[1] Good Words, Feby. 1865.
[2] Haughton on a New Theory of Muscular Action, p. 16.

The mean of this Table gives 762,048 foot-pounds. A man's labour differs within a tolerably wide range, according to the manner in which it is exerted, for while it may not exceed 480,000 foot-pounds in hammering, it may reach to 1,500,000 foot-pounds when pushing or pulling horizontally.[1] Hence the amount of 792,000 foot-pounds taken for a day's work, may be considered a full, though not an excessive amount.

This estimate receives further support when we examine the work performed by soldiers in war. In Sherman's famous march from Atlanta to Savannah, twelve miles daily were accomplished. In war, the Prussian army walks fourteen miles daily, resting every fourth day. In our Indian marches, twelve miles daily, with the same rest, is the rate of work allowed to the troops. Hence, if we take full war work as represented by fourteen miles' daily continuous marching, the soldiers being laden with sixty lbs. weight of accoutrements,[2] we have a full estimate of labour work. This is found by the following equation—

$$\left(\frac{150 + 60}{20}\right) \times 73920 = 776{,}160 \text{ foot-pounds.}$$

The weight of the man and of his accoutrements, divided by the co-efficient of traction, and multiplied by the number of feet traversed, thus leads us to a result rather less than that found for the pedestrian. The following Table gives the dietetic value for soldiers engaged in the arduous duties of war:—

[1] Ranken, Applied Mechanics, p. 610. [2] Parkes Hygiène, p. 369.

TABLE III.—DIETARIES OF SOLDIERS DURING WAR.

COUNTRIES.	Weight of Solid Food.	Flesh-formers.	Fat.	Starch, Sugar, etc.	Starch Equivalent.	Mineral Matter.	C Carbon in Flesh-formers.	C′ Carbon in Heat-givers.	Total Carbon, C+C′.	Ratio C:C′::1:x	Ratio of Flesh-formers to Starch Equivt.
	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.
England (Crimean War),[1] .	41·05	4·53	2·05	16·00	20 88	0·61	2·43	8·68	11·11	3·57	4·60
,, (Kafir War),[1] . .	47·4	5·74	2·94	16·00	23·03	0·73	3·08	9·36	12·44	3·03	4·01
France (Crimean War),[2] .	59·75	6·49	3·59	21·37	29·90	0·90	3·49	12·25	15·74	3·51	4·60
Prussia (Schleswig War),[3] .	48·0	5·90	1·60	21·41	25·26	0·84	3·17	10·73	13·90	3·38	4·28
Austria (Italian War),[4] . .	38·6	5·15	2·58	21·47	26·24	0·51	2·77	11·51	14·28	4·15	5·09
Russia (Crimean War),[5] . .	42·6	4·99	2·54	14·55	20·37	0·65	2·68	8·41	11·09	3·13	4·08
Holland (Belgian War),[6] .	28·4	4·33	1·40	13·87	17·22	0·40	2·32	7·23	9·55	3·11	3 97
Federal Army, 1865,[7] . .	57·2	5·60	2·48	17·70	23·46	0·80	3·01	9·76	12·77	3·24	4·18
Confederate Army, 1865,[8] .	50·0	5·95	2·56	18·96	25·03	0·71	3·20	10·38	13·58	3·24	4·20
MEAN OF WAR DIET, . .	**46·0**	**5·41**	**2·41**	**17·92**	**23·48**	**0·68**	**2·90**	**9·81**	**12·71**	**3·37**	**4.35**

[1] Report of Sanitary Commission on the State of the Army, p. 427.
[2] Code des Officiers de Santé, 1862.
[3] Das Preuss. Militair Med. Wesen. p. 159.
[4] Parke's Hygiène, p. 148.
[5] Rep. San. Com. p. 425.
[6] Mulder's Ernahrung, p. 58.
[7] Rep. American Sanitary Commission, p. 77.
[8] From an Officer of the 22d Louisiana Regt.

Hence it will be observed that about 5·5 oz. of flesh-formers, and 23½ oz. of the starch equivalent of heat-givers, are required by the soldier to enable him to withstand the fatigues of war.

10. We possess in the English army a corps of soldiers who are labourers even during peace. I allude to the Royal Engineers, who, while in the depôt at Chatham, are actively occupied either in constructing field-works, or in pursuing their avocations as artisans, from which class they are all selected. Desirous to obtain the dietaries of these men, I applied to Colonel Collinson, R.E., the second in command at Chatham, and he, with the consent of Colonel Harness, instituted a careful inquiry into the actual amount of food consumed by 495 men for twelve consecutive days. Quarter-Master Conolly took an active part in the inquiry, and the captains of each of the companies became responsible for the accuracy of the returns, which were made with all the detail and care to be expected from this highly scientific corps. These returns were then reduced to their dietetic value by myself, so that we may consider them as affording the most complete evidence which we possess of the requirements of food for labouring men during a fair but not an excessive amount of work in twenty-four hours.

TABLE IV.—DIETARIES OF THE ROYAL ENGINEERS FROM 1ST TO 12TH JANUARY 1865.

NAMES OF COMPANIES.	No. of Men giving returns.	Weight of solid food.	Flesh-formers.	Fat.	Starch, Sugar, etc.	Starch Equivalent.	Mineral Matter.	C Carbon in Flesh-formers.	C′ Carbon in Heat-givers.	Total Carbon, C+C′.	Ratio C:C′::1x.	Ratio of Flesh-formers to Starch Equivalent.
		oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.	oz.
8th Company, . . .	30	68·6	5·37	2·68	22·96	29·37	0·90	2·889	12·257	15·146	4·24	5·47
23d ,, . . .	56	73·75	5·65	2·65	23·63	29·62	0·98	3·039	12·531	15·570	4·12	5·24
35th ,, . . .	90	64·22	4·84	2·94	20·24	29·24	0·83	2·603	11·250	13·853	4·32	6·04
36th ,, . . .	80	63·16	4·83	3·66	20·83	29·80	0·87	2·598	12·066	14·664	4·64	6·17
37th ,, . . .	67	68·2	5·39	2·64	22·70	29·31	0·87	2·899	12·111	15·010	4·17	5·43
38th ,, (Chatham),	20	68·4	4·84	3·45	22·92	30·74	0·87	2·603	12·832	15·435	4·92	6·35
38th ,, (S. Kensington),	9	63·0	4·16	2·72	20·99	27·46	1·25	2·238	11·413	13·651	5·09	6·60
39th ,, . . .	68	71·2	5·27	2·63	23·19	29·35	0·96	2·835	12·321	15·156	4·34	5·57
40th ,, . . .	75	62·2	5·34	2·89	22·56	29·58	0·84	2·872	12·241	15·113	4·26	5·54
MEAN OF ALL RETURNS, .	495	66·97	5·08	2·91	22·22	29·38	0·93	2·730	12·113	14·844	4·45	5·82

There are several points of interest shown by these reductions. The working soldier finds it necessary to take about five oz. of flesh-formers daily. The only notable exception is in the case of a detachment of the 38th Company, stationed at the South Kensington Museum. This exception furnishes a ready explanation, for although these soldiers are even better paid than those at Chatham, their work is of a less laborious character, being chiefly that of draughtsmen, photographers, etc.; with this work they do not require a larger quantity of flesh-formers than is consumed by soldiers of the line, and accordingly we find that their diet sinks to this level.[1] Omitting this exceptional case, we find a singular uniformity in the starch equivalent of heat-givers. It is higher than that of soldiers engaged in war, but this is doubtless due to the ease with which potatoes are obtained in garrison, and to their being always in considerable quantity in the diet.

11. We do not possess many well-recorded instances of labourers' diets, by actual weight and measure. The approximative returns obtained by Dr. E. Smith, in his report to the Privy Council on the diet of the working classes, are valuable for what they profess to be, as giving us an insight into the mode of living of artisans; but they can scarcely be considered as presenting us with data of weight and measure, ascertained with any further degree of precision than could be obtained by conversation with working people. I append a few instances of working dietaries, which have been determined by actual weights of the food consumed :—

[1] For this return I am indebted to Captain Donelly, R.E., Inspector of Science to the Department of Science and Art.

Table V.—Examples of Labourers' Dietaries.

Class of Labourer.	Flesh-formers.	Fat.	Starch, Sugar, etc.	Starch Equivalent.	Carbon.
English sailor (fresh meat),[1]	5·00	2·57	14·39	20·40	11·05
French sailor,[2]	5·74	1·32	23·60	26·70	14·58
English navvy (Crimea),[3] .	5·73	3·27	13·21	21·06	11·46
,, ,, (Rouen Railway),[4]	6·84	3·82	27·81	37·08	18·96
Hard-worked weavers,[5] . .	5·33	1·53	21·89	25·42	13·76
Fully fed tailors,[6]	4·63	1·37	18·47	21·64	11·74
Blacksmiths,[7]	6·20	2·50	23·50	29·50	15·69
Mean Working Diet,	**5·64**	**2·34**	**20·41**	**25·97**	**13·89**

I have not quoted in this table the well-known allowances of 910 lbs. oatmeal given annually to our Scotch agricultural labourers on the bothy system, and 60 oz. of milk daily. This diet equals 8¾ oz. of flesh-formers, 4·5 oz. of fat, and nearly 27½ oz. starch. I attach little importance to this, because it is well known that the labourer sells nearly a quarter of the oatmeal to buy spirits and other luxuries. A man training for prize-fighting,[8] and who walked seventeen miles daily for exercise, was found to eat weekly 269 oz. of mutton, without bones, 14 oz. of bread (only 2 oz. daily at dinner), and 170 oz. of ale. The food of this prize-fighter had therefore the following dietetic value :—

[1] Advantages of Entering British Navy. Bradbury and Evans, 1854.
[2] Payen, Substances Alimentaires, p. 322.
[3] Dietary to Navvies Employed in making the Railroad in the Crimea (Letheby), Soc. Arts Journ. 1863.
[4] Gasparin, Cours d'Agriculture.
[5] Dr. E. Smith, Phil. Trans., vol. 151, p. 747, *et seq.*
[6] *Idem.*
[7] Food consumed by a blacksmith ; mean of two days.
[8] Percy on Fæces.

Flesh-formers, ...	9·8 oz.
Fat, ...	3·1 „
Starch, ...	3·27 „
Starch equivalent, . . .	10·70 „

This result, however, is certainly not an average case, although interesting as showing the conditions employed in training a man to the extreme of muscular activity.

12. From the preceding data we propose to take the following general averages in our calculations :—

	Subsistence Diet. oz.	Diet in Quietude. oz.	Diet of Adult in Full Health. oz.	Diet of Active Labourers. oz.	Diet of Hard-worked Labourers. oz.
Flesh-formers,	2·0	2·5	4·2	5·5	6·5
Fat, . . .	0·5	1·0	1·8	2·5	2·5
Starch, . .	12·0	12·0	18·7	20·0	20·0
Starch equivt,	13·2	14·4	22·0	26·0	26·0
Carbon, . .	6·7	7·4	11·9	13·7	14·3

Division II.

Application of the Preceding Data to Elicit the Source of Useful Work.

13. The common experience of mankind teaches us, that when work is to be obtained from an animal, it must be supplied, in proportion to the labour, with food rich in flesh-formers. Thus a horse, when at work, must be fed with oats or beans, both rich in flesh-formers ; a

supply of potatoes or turnips, both abounding in heat-givers, would not enable it to do its work. Professor Dick, the head of the Veterinary College in Edinburgh, tells me that a horse may be kept without work, but taking a little exercise, in fair condition, on 12 lbs. of hay and 5 lbs. of oats ; but if a good amount of work is to be got out of it, the horse should get 14 lbs. hay, 12 lbs. oats, and 2 lbs. beans. These diets reduced, as regards their flesh-formers, are as follows :—

Horse at rest, ...	29·2	oz. of flesh-formers.
Horse at work, ...	56·2	„ „ „
Diff. for work, . . .	27·0	„ „ „

The labour of a horse is generally taken as equal to that of between seven and eight men ; and as the working food of a labourer is $5 \cdot 5 - 2 \cdot 0 = 3 \cdot 5$, the proportion

$$3 \cdot 5 : 27 :: 1 : x,$$

in which $x = 7 \cdot 7$ leads to the same result. Again, if we compare the labour and food of a horse and of a man when doing the same kind of work, that is, pulling weights horizontally, we have the following ratios, which, from the different character of their food and assimilative processes, must be made upon the flesh-formers actually expended on work external to their body :—

$$\frac{\text{Work of horse, Morin,[1]}}{\text{Work of man, Rankin,[2]}} \quad \frac{12.400,000}{1,500,000} = 8.$$

$$\frac{\text{Labour flesh-formers in the food of horse,}}{\text{,, ,, ,, food of man,}} \quad \frac{27}{3 \cdot 5} = 7 \cdot 7.$$

These ratios are as near as we can expect with animals of such a different character. If we take again two labouring animals of the same herbivorous nature,—the ox and horse,—we can compare their labour and

[1] Morin, Mech. trans. by Burnett, p. 397.
[2] Ency. Brit., Article "Mechanics."

food without complicating the question by deducting the quantity required for *opus vitale.* Experience shows that an ox is well fed on 50 lbs. mangold-wurzel, 3 lbs. beans, and 17 lbs. wheaten straw, the flesh-formers in this food being 38·6 oz. Muschek[1] has given us the labour of an ox, from which we obtain the following ratios :—

$$\frac{\text{Work of horse in foot-pounds,}}{\text{Work of ox} \quad ,,} \quad \frac{12{,}400{,}000}{8{,}640{,}000} = 1{\cdot}43.$$

$$\frac{\text{Plastic food of horse,}}{,, \quad \text{food of ox,}} \quad \frac{56{\cdot}5}{38{\cdot}6} = 1{\cdot}46.$$

14. These numbers, so far as they go, appear to indicate that the external dynamical work of animals is proportional to their plastic food. But this is only the common experience of man. The miners in Chili, who work like horses, also feed like them, for Darwin tells us that their common food consists of bread, beans, and roasted grain. During our harvests in Scotland, the reapers consume about 8 oz. of plastic nutriment daily (Christison). Our railway contractors know this necessity of the system so well that they are accustomed to discharge labourers when their appetites fail (Lankester). And, generally, the previous diet-tables prove this amply, by showing a constant increase of 30 per cent. of flesh-formers in a labouring diet over one fitted for health without hard work, as contrasted with a varying increase of from 5 to 20 per cent. in the heat-givers.

15. Having thus rendered it probable that we are to look to the plastic ingredients of food as exponents of dynamical action, both internal and external to the body of a man, let us now examine the transformations which they suffer. All chemists are agreed that the final

[1] As quoted in Ranken's Mechanics.

transformation of plastic matter in the body yields carbonic acid, water, urea, and sulphuric acid. Those who believe that the transformation takes place in the blood, agree on this point with those who consider that it is effected in the tissues.

If we therefore take the simplest possible *empirical* formula for albumen, or of tissue formed by it, one representing analysis merely, and not constitution, our views may be more easily understood. Such a formula is $C_{24}H_{38}N_6O_{16}$, in which the 1·2 per cent. of sulphur is for the present supposed to play the part of oxygen.

		Calculated.	Mean of Analyses.
24 C, . .	288	53·55	53·8
38 H, . .	38	7·06	7·0
6 N, . .	84	15·61	15·7
16 O, . .	128	23·78	{ S 1·2 O 22·3
	538	100·00	100·0

The transformation of this generic tissue-forming body, still omitting the sulphur, would be as follows :—

Albumen.	Urea or Amido-carbonic Acid.	Carbonic Acid.	Water.

$$C_{24}H_{38}N_6O_{16}+100\ O=3\ (CO_2(NH_2)_2)+21\ (CO_4)+13\ (H_2O_2).$$

The simplicity of the transformation is remarkable. Water and two forms of carbonic acid are alone produced ; of the latter amido-carbonic or urea is secreted with water *per vesicam*, and the gaseous carbonic acid, accompanied by watery vapour, passes away *per halitem* or *per cutem*. If this empirical formula be a fair representation of analysis, and it claims to be nothing more, then, as the result of the transformation, *seven* times as much carbon should escape by the lungs and skin as by

the urine. We can only test this when animals are fed on a flesh diet free from fat. Luckily there are two classes of experiments of this kind, one of them being by Bischof and Voit,[1] and the other by Pettenkoffer and Voit.[2] The results of the former, omitting the starving experiments on the dog, are as follows :—

	Grammes of Flesh.	C in Urea.	C in CO_2.
		Grammes.	Grammes.
First Series, . .	1800	24·2	180·8
Second ,, . .	1500	21·6	162·1
Third ,, . .	1200	17·7	132·6
Fourth ,, . .	1800	24·9	186·5
Fifth ,, . .	1800	25·6	223·3
Sixth ,, . .	2000	30·3	228·5
MEAN, . . .	1383	24·0	185·6

Before using these figures, we must correct them, for the one per cent. of fat which, according to these authors, still remained in the flesh. If we suppose the fat to contain 77 per cent. of carbon, then 13·83 grammes of fat, in the average daily supply of 1383 grammes of flesh, would contain 10·6 grammes of carbon. Hence we have in reality 175 grammes of the carbon in the carbonic acid due to the flesh alone. From this we obtain the ratio—

$$24 : 175 :: 1 : x \; . \; . \; . \; . \; . \; . \; . \; x = 7{\cdot}29.$$

In Pettenkoffer and Voit's experiments, conducted in a like way, but where no correction requires to be made for fat, 21·6 grammes of carbon were found in the urea,

[1] Die Gesetze der Ernährung der Fleischfressers, S. 61, *et seq.*
[2] Ann. der Ch. und Phar. Supp. Bd., 1863.

and 148 grammes in the carbonic acid, and small quantity of carburetted hydrogen, which escaped by the lungs and skin. Hence we have—

$$21 \cdot 6 : 148 :: 1 : x \ldots\ldots x = 6 \cdot 85.$$

The mean of these two independent series of experiments shows that 7·07 times as much carbon passes away in the form of carbonic acid as we find in urea, our equation having required 7·0.

16. Having established the fairness of the equation of transformation, we have to ascertain its calorific value. Although we are well aware, as has been shown by Berthelot[1] and others, that this depends for absolute truth on a thorough knowledge of the rational constitution of a body, this need not prevent, until the progress of knowledge teaches us this, our use of approximative numbers. These we can obtain by the following scheme :—

21 C	become	21 CO_4,	Carbonic acid.
3 C	„	3 CO_2,	Carbonic oxide.
26—16 H	„	5 H_2O_2,	Water.

In this scheme the hydrogen is reduced to ten atoms, because there are already sixteen atoms of oxygen in the tissue, which may be supposed to have united with that element without increase of temperature. The calorific units employed are those of Andrews, viz., 7,900 for carbon, 33,808 for hydrogen, and 2,307 for the 1·2 per cent. of sulphur in albumen. We do not know experimentally how much heat is given out when carbon unites with oxygen to produce carbonic oxide, but as we do know how much the latter gives out on becoming carbonic acid, it is easy to calculate how much heat a

[1] Acad. de Science, January 1865.

gramme of carbon would evolve on becoming carbonic oxide. The unit of heat by this calculation would be 2227·7. It will now be convenient to ascertain by these numbers how much heat would be given out by the transformation of one ounce or 437·5 grains[1] (28·35 grammes) of tissue. A little calculation shows that this quantity would yield as much heat as would raise 126·5 kilogrammes of water 1° C. This, converted into its mechanical equivalent, gives :—

$$126{\cdot}5 \times 425 = 53{,}762 \text{ metre kilogrammes.}$$

17. These numbers can easily be applied. Thus we have seen that a labourer receives 5·5 oz. (155·92 grammes) of flesh-formers in his food. The potential energy represented by this quantity is 295,691 metre kilos. ; while the man's labour of raising his own weight one mile high per day is 109,496 metre kilos. But we have not yet deducted the amount of energy required for *opus vitale,* in which we include internal, dynamical, mental, and assimilative work. Concurring estimates

[1] The details of this calculation are as follows :—

One ounce of albumen contains—

Carbon,	235·37	grains.
Hydrogen,	30·62	,,
Nitrogen,	68·68	,,
Sulphur,	5·25	,,
Oxygen,	97·56	,,
	437·48	

This, treated according to the equation given :—

C.	201·75	×	7,900 =	1,593,825
C.	33·62	×	2,227·7 =	74,895
H.	8·05	×	33,808 =	272,154
S.	5·25	×	2,307 =	12,111
				1,952,985

$\dfrac{1{,}952{,}985}{1 \text{ kil.} = 15{,}432 \text{ grs.}} = 126{\cdot}5$ kilogramme units. To convert this into mechanical force :—

$$126{\cdot}5 \times 425 = 53{,}762 \text{ metre kilos.}$$

of the force exerted by the heart have been made by Helmholtz[1] and Haughton.[2] The latter estimates it at 122 foot-tons, or 273,280 foot-pounds, which is more than one-third of the useful work done out of the body. Now, although the motion of the blood in the human body depends almost entirely upon the heart, there are at least indications in man, and clear evidences in plants,[3] and in the lower animals, that there are other movements in the system without any *vis a tergo* from an impelling body. If the heart do not use the energy placed at its disposal more economically than the conscious man does the amount with which he works, then it would require nearly one ounce, or exactly 1·20 oz. (theoretically, 0·702 oz. should suffice) of the plastic food. This is very nearly one-half of that which is required for subsistence. The two ounces of flesh-formers used in subsistence would yield by their transformation 253 units of heat, or a mechanical equivalent of 107,524 metre kilos., while the work of the heart is only 37,781 metre kilos. But in addition to the other dynamical work within the body, there is also included in this subsistence quantity both a limited amount of mental work and a full proportional of assimilative work. In the dynamical work, besides the cardiac movements, there are those of the respiratory apparatus, of the diaphragm, of the intestines, and of the arteries. All these in the aggregate represent a considerable, though numerically unknown, demand upon plastic food. And finally, we have the mental work, not considerable certainly in a man fed upon a minimum diet, but probably requiring a certain

[1] Lectures at Royal Institution, Lect. VI.
[2] New Theory of Muscular Action, p. 23.
[3] Carpenter's Physiology, p. 215.

amount for the manifestations of mind to the material world. We cannot therefore be surprised to find that double the amount of energy necessary for the cardiac movements is supplied for the whole functions included in *opus vitale.*

18. The *opus mechanicum* or external dynamical work done by the body of a hard-worked labourer, is to be sought in the 3·5 ounces (99·2 grammes) of flesh-formers which remain after deducting the amount required for *opus vitale* from the total plastic food. But of this quantity one-twelfth appears in the alvine evacuation, without being formed into tissue, and the remainder yields 405 units of heat, or its mechanical equivalent of 172,125 metre kilos.; while the actual amount of useful work performed by the man is 109,496 metre kilos.

19. When we contrast the useful work of a steam-engine with the potential energy supplied to it, this economy of force on the part of the man must appear surprising. But even in the rough mode of calculation available to Scoresby and Joule, to Dumas and Helmholtz, before our knowledge of dietetics had enabled us to consider this question in a more precise way, the relative economy of the human machine excited their surprise. And yet our demand for economy is much greater than they supposed to be necessary, for we require that more than half of the potential energy should be converted into useful work.[1] It may be therefore necessary to adduce general arguments in support of the view that the dynamical action of the body depends wholly on the transformation of the tissues.

[1] It would take from 1000 to 1200 grammes of coal burned in a steam-engine to raise a man from the level of the sea to the top of Mont Blanc; but the same man could do this work in two days by the transformation of 198·4 grammes of dry muscle.

20. Nothing is better established in physiology than that muscular activity is dependent on a free supply of arterial blood to the muscles. When a ligature is applied to a large arterial trunk, the action of the voluntary muscles depending on that vessel is either wholly or partially arrested, at least until the collateral circulation is developed. Thus when the abdominal aorta is tied in animals, their hind legs can scarcely be dragged along (Segalus).[1] Such experiments only prove that a free supply of arterial blood to the muscle, to promote its transformation and to restore its waste, is necessary for the production of muscular action. Anything that interferes with the oxidising influence of the blood upon the substance of the muscle affects the power of movement. In the cerulean disease, when venous and arterial blood become mixed, the patient shows both indisposition and inability for muscular exertion. Like difficulty is observed in the thin air of mountain tops, until the lungs become suited to it. Certain substances which retard the oxidation of phosphorus or phosphuretted hydrogen, even in the presence of oxygen (Graham), such as ether and chloroform, seem to act in a like way on the tissues of an animal, by arresting muscular effort. The proof that there is diminished oxidation in such cases is found in the presence of sugar in the urine. The wayward gait of the drunkard under the influence of alcohol is probably the result of a similar obstacle to change.

Gustav von Liebig[2] has demonstrated that the oxidation of tissue is quite essential to muscular irritability, which ceases when the access of oxygen is prevented,

[1] Journ. de Phys., 1824.
[2] Inaugural Abhand. Giessen, 1853.

and is again manifested when it is supplied. Sczelkow's[1] experiments on the gases of the blood are particularly interesting in this point of view. Arterial blood contains 17 vols. of oxygen and is reduced to 8 vols. in coursing through a muscle at rest, and to between 1 and 2 vols. when the same muscle is in action, the volume of carbonic acid augmenting from 24 to 34½ at the same time. These experiments prove clearly that oxidation and contemporaneous production of carbonic acid attend the transformation of tissues, a fact which other physiologists had shown with less numerical precision formerly. Thus Matteucci,[2] in confirming the fact that muscular contraction is dependent on the presence of oxygen, showed that the evolution of carbonic acid is proportional to the amount of contraction, a result which has been confirmed by Valentin.[3] We need scarcely adduce proofs that the oxidation and production of carbonic acid proceed simultaneously in the substance of the tissue and not in the blood, for as long as the muscle is contractile, after it has been cut off from the blood, the same changes go on. Again, in insects which have no true blood, carbonic acid is produced by muscular activity (Newport).[4] Valentin[5] observed that when muscular contraction takes place a greater volume of oxygen is absorbed than of carbonic acid evolved, a result to be expected when we know that hydrogen is oxidised and urea is formed. Helmholtz attempted to follow the changes in a contracting muscle, and found evidence of increasing lactates, but could find no diminution in the fat contained in it, a fact of great significance, as we shall

[1] Sitz. Wiener Acad. 1862.
[2] Comptes Rendus, xlii. 648.
[3] Müller's Archiv. 1845, S. 72.
[4] Phil. Trans. 1836.
[5] Archiv. fur Heilkunde, xiv. 431.

see hereafter. Brown Sequard,[1] by producing a circulation of arterial blood in the body of an animal which had assumed cadaveric rigidity, showed that muscular relaxation and contractility was restored and preserved for a long time, the blood issuing as venous; and he further proved that the elongated condition of muscles required the presence of oxidised blood. I have made experiments along with Mr. Turner, the Demonstrator of Anatomy in the University of Edinburgh, to ascertain whether oxygenated water (peroxide of hydrogen), or a solution of permanganate of potash, would cause relaxation in the muscles of rabbits after *rigor mortis* had set in, as Richardson found. In four rabbits these supplies of oxygen had no effect whatever, either in preventing the access of *rigor mortis* or in relaxing it. I believe therefore that this relaxation is not due merely to the oxidation of the muscle, but to its nutrition by the arterial blood, which feeds it while it removes the effete matter. It will be obvious from the tenor of my remarks, although I am unwilling to complicate the present question by a theory, that I agree with Draper[2] and others, in considering the contraction of a muscle due to a disintegration of its particles, and its relaxation to their restoration, agreeing also with Dr. Radcliffe[3] as to the active state of the relaxed muscle and the exhausted state of the contracted, without assenting, however, to his torpedo discharges as the causes of these states.

21. All these facts prove that transformation of the muscle through the agency of oxygen is the condition of muscular action. Most likely intermediate products are

[1] Gazette Médicale, 1851, and Croonian Lecture, R. S., 1861; compare also Stannius, Vierordt's Archiv, 1852.
[2] Human Physiology, p. 446.
[3] Lectures on Epilepsy, 129.

formed before the final forms of carbonic acid and urea are reached. If these graduated changes take place in the muscle itself, the same amount of potential energy will be available as would be if the simplest forms of oxidation were reached at a bound. If lactic acid be the intermediate product of oxidation before carbonic acid, its passage into the latter must be very rapid, for that is continually eliminated from a muscle during its action. And if we thus constantly find that carbonic acid, the highest oxidised form of carbon, is manifested in the substance of muscle during its activity, it is certainly to be expected, that the less oxidised form of amido-carbonic acid should be simultaneously produced. In those cases of disease where elimination of urea is retarded, it is found abundantly in the muscles. Thus, in cholera, especially in the muscles which have been severely cramped, urea is detected with ease. In this disease there is a small amount of chloride of sodium in the blood, and its solvent action on the urea is thus reduced. In uræmia, also, it can readily be extracted from muscular substance.[1] Although in the muscles of certain kinds of fish, as in the *Plageostomata* (Frierichs and Städeler), urea may be always found, yet Liebig[2] searched for it in vain in the muscles of healthy mammals. Yet this is not surprising, when we consider how long search was made for urea in the blood without success. Although the blood contains the sum of the urea of all the transformations proceeding throughout the body, yet as Marchand[3] has shown, the quantity of it which can exist in the blood at any one time is so small that it may readily

[1] Buhl und Voit, Zeitsch. fur rat. Med. vi. 94; and Von Bibra, Ann. der Ch. und Phar. xciv. 206-215.
[2] Chemistry of Food, p. 142.
[3] Pogg. Ann. xxxi. 303.

escape detection. If this be true in regard to blood, it is *a fortiori* true in respect to flesh from which the blood is rapidly removing waste matter in the process of the reparation of the exhausted muscle. It may be possible that creatin[1] is intermediate between tissue and urea, but this is a pure speculation; for although we are acquainted with processes by which it can be split into sarkosin and urea, we know of no simple oxidation which will effect this change. Let us inquire how much urea we may expect to find in flesh in a given time, and it will not appear wonderful that it has escaped detection even in the skilled hands of Liebig. In an adult man, 520 grains of urea are secreted in twenty-four hours; hence in one hour $\frac{520}{24} = 22$ grains. Now, although we know that blood is incessantly and promptly removing waste material from the muscles, let us suppose that a quarter of an hour elapses without any of it being taken up, and that the man is killed at this period. Distributed through all the muscles of his body there would be about 5 grains of urea; and in 10 pounds' weight of fresh flesh, the quantity operated upon by Liebig, there could not be more than 0·4 grain of urea, or 0.026 gramme. In this estimation we take the weight of fresh flesh at 1800 ounces. In our present state of analysis for urea this small quantity could not be detected.

22. In considering the origin of energy in the muscles, one of three sources is alone conceivable—(1.) The energy might arise in the circulating fluid itself; or, (2.) The oxygen of the blood might consume the fat deposited in the muscle; or (3.) The substance of the muscle must be transformed to provide the energy.[2]

1 Schottin Archiv. fur Heilkunde, 1860, 417.

2 We do not consider it necessary in the present state of science to present a fourth alternative of the origin of the energy from "nervous force."

We have already (§ 20) shown that the changes which take place in muscle during contraction occur in its substance, and not in the circulating fluid of the capillaries, for irritability continues for a considerable time after the blood has been cut off; and we might here recall the well-known fact, that in spite of a larger quantity of oxygen being taken into the lungs than of carbonic acid evolved, and consequently a necessary evolution of latent heat, the blood of the left side of the heart is 0·2 degrees cooler than that of the right side, showing that oxidation of material is not largely effected during aëration of the blood. We may therefore proceed to the second possible source of energy—the combustion of the fat in the substance of muscle.

23. The usual function of fat is unquestionably, like that of starch or of sugar, to keep up the heat of the animal. When they have served this purpose their physiological work is completed, and the *opus calorificum* cannot be changed into *opus mechanicum*, for that must be due to converted heat, or to force, which has never assumed that form. We know that all the fat

Some old experiments of Matteucci are still, however, constantly quoted in support of this view. He says (Phys. Phen. of Living Beings, p. 325) that the chemical action of three milligrammes of zinc, oxidating and converted into nervous force, in a frog, produced a muscular power equal to 5·419 metre kilos. But the current emanating from the zinc could only have exercised a directive action on the muscle which it affected. The total energy derivable from the zinc can be found as follows :—

$$\left(\frac{003 \times 1301}{1000}\right) \times 420 = 1 \cdot 64 \text{ metre kilos.}$$

Deducting this from 5·42, actually got in the experiment, 3·78 metre kilos. of work must have been obtained from some other source of energy beyond the zinc. There is no other source than the substance of the muscle itself. So long as a muscle is alive and in contact with oxygen it can contract under electrical excitement, and the difference between the work which could be done by the exciting force and the useful work obtained, must be the measure of the energy rendered available by the structural and molecular change of the muscle itself. In a later memoir (Phil. Trans. 1857), Matteucci compares the exciting current to the spark which ignites gunpowder, and would seem to have abandoned his former ideas.

and starch in food is required to account for the animal heat, because it has always been a difficulty to reconcile the experimental heat actually generated by an animal with the amount available in the food-fuel supplied to it. In fact, until the researches of Andrews, and of Favre and Silberman, gave to us higher calorific values for hydrogen and carbon than formerly, there was no possibility of accounting for the heat actually given out by animals in the experiments of Dulong.[1] And even with these increased co-efficients, we require the combustion of all the non-nitrogenous constituents of food to enable us to account for animal heat. But although this is the case, we must bear in mind that only a small quantity of converted heat is theoretically necessary for mechanical work. The energy available in 22 oz. of a starch equivalent of fuel, consumed by a healthy man, would correspond to 2187 kil. units of heat; while the transformation of the muscles of that man, required for mechanical force, yields about 543 kil. units. Although nearly one-half of the latter is spent in internal dynamical work, and passes into heat within the body, still we cannot afford to subtract any of the available work from the heat-givers. Taking it in round numbers, we have 2500 kil. units of heat available from them and converted vital work, and 2700 kil. units are required, according to the estimate of Helmholtz, to account for evaporation, heating of the ingesta, and radiation. The diversion therefore of the ordinary ingredients of food, whose proper function is *opus calorificum*, to the production of *opus mechanicum*, is not probable from *à priori* considerations. But it is nevertheless a fact that fat is

[1] Berl. Med. Ency., Art. "Thierische Wärme;" compare also Fick, Med. Physik, S. 175, *et seq.*

always present in healthy muscle, and it is desirable to consider its relation to muscular action.

24. The experiments made by Bidder and Schmidt[1] on starving cats, and by Bischof and Voit on a starving dog,[2] throw light on this subject. From these we learn that during the whole course of starvation, fat disappears from the muscle in a regular manner, while there is no such regularity as to the waste of the tissues. The amount of urea falls to one-half in two days; then remains constant for a week, falling again rapidly and considerably two days previous to death; during all this time the daily waste of fat remains nearly constant. Nor is there anything surprising in this difference. As the animal becomes weaker, the internal dynamical or vital motions decrease, and their representative in the urine naturally falls. But the fat continues to burn in the living lamp, as steadily as the lungs afford to it oxygen.

When Bischof and Voit supplied their starving dog with fat, the waste of the body, as evidenced by the lessened amount of urea secreted, was diminished, because the fat supported the respiration, which before had partially to depend on wasting tissues. The fat cast over them a protective influence, and limited their waste to the support of their own dynamic functions. And in this fact would seem to be the use of fat after it is stored up in the muscle. We allude to its chemical use; for its mechanical advantage in lessening friction, and its possible histogenetic employment in the formation of cells, are not under consideration. Fat does not form a portion of an organ, for ether can ex-

[1] Das Stoffwechsel, 1852.
[2] Die Gesetze der Ernährung, etc., p. 97, *et seq.*

tract it without any lesion of the organic structure. In wild animals the muscular fat is present in only small proportion—not exceeding two per cent. of the muscle. In the muscle of an active man, the fat amounts to 2·2 per cent. A man in ordinary health and activity wastes daily 1750 grains of dry flesh, or 7000 grains of fresh muscle, which would contain 150 grains of fat. The total amount of heat, which this quantity could yield by its combustion, is 87 kil. units, while the flesh in which it resides would give by its transformation about 506 kil. units. We need not therefore look for the source of potential energy in a minor when we have a major source quite sufficient to account for it. The human heart weighs on an average 9·4 oz., and contains, according to Böttcher, a mean of 1·7 per cent. of fat. On the extravagant supposition, in § 18, that it destroys more than half its substance daily in movements, it would use 147·7 grammes, containing 2·5 grammes of fat. This quantity could by its combustion give 23·9 kil. units of heat, or 10,157 metre kil. of mechanical force. But we have shown that the useful work of the heart is 37,780 metre kils. So that the fat cannot account for the work performed. In these calculations we refer to fat distributed in and inherent to healthy muscle, and not to masses of fat in adipose tissue, such as we find in fattened animals or obese men, for no one pretends that such separate fat can be the cause of movement in any other sense than that starch, sugar, or other body extraneous to the muscle, may, by some unknown or inconceivable method, have this force transformed from *opus calorificum* to *opus mechanicum.* The chemical use of fat deposited within the muscle may be to protect it from the assaults

of oxygen during its repose. A muscle, even at rest, gives out carbonic acid, which is no doubt partly due to the oxidation of its effete particles, but also to the oxidation of fat. The conception that the latter is the source of muscular action can only have arisen from the false analogy of the animal body to a steam-engine. But incessant transformation of the acting parts of the animal machine forms the condition for its action, while in the case of the steam-engine, it is transformation of fuel external to the machine which causes it to move.

25. From the considerations which have preceded, we consider Liebig amply justified in viewing the non-nitrogenous portions of food as mere heat-givers. They never can act vicariously for albuminous bodies as tissue-formers, although tissues may and do evolve heat by transformation when required to do so. That heat-givers do operate indirectly on the waste of tissues cannot be questioned. They facilitate transformation, by keeping up animal heat and by the promotion of circulation. Cold-blooded reptiles become more active when artificial warmth is supplied to them, and conversely, warm-blooded mammals become more sluggish when the heat of their bodies falls, as during hibernation. Such dependencies of different groups of food, acting co-ordinately, are incessantly found, but nevertheless each group has its own specific work to perform.

26. While we have been led to the conclusion that the transformation of the tissues is the source of dynamical power in the animal, we have yet to examine whether the occurrence of heat, and electro-motive force current in the muscles, may not be evolved from and thus absorb the force on which we have relied. The muscle during

contraction is certainly hotter than at rest, about 0·5° C. warmer, according to Becquerel and Brechet. In fever, the temperature of the muscles rises sometimes to 40° or 41° C., and in tetanus to 44° C. (Ludwig) ; while Fick has shown that in these cases the muscles are hotter than the circulating blood. But the experiments have been made when the waste of tissue is not producing useful work, and must therefore necessarily pass into heat. Beclard[1] found in fact that the heat developed in a muscle is in inverse ratio to the mechanical effects produced ; for example, in trying to raise insuperable weights, more heat is evolved than in lifting lighter weights. Hirn[2] also ascertained, by direct experiment on a tread-mill, that less heat is evolved for each gramme of oxygen taken into the body when hard work is done outside the body. In fact, the heat developed in muscles, when not due to the combustion of fat, is probably only the result of lost work, just as we find that the electromotive force disappears almost entirely during the active work of a muscle or nerve[3] (Du Bois Raymond). Even with the wonderful economy of force which the animal as a machine exhibits, we cannot be surprised that some of the lost work is manifested in the forms of heat and electricity. We know, for instance, that all the potential energy rendered available for internal dynamical work must assume ultimately these forms.

[1] Comptes Rendus, 1860, i. 471.
[2] Théorie Mécanique de la Chaleur, i. 34.
[3] Untersuchungen uber Thierische Electricität, Bd. ii., 511.

Division III.

Secretions as Measures of Work.

A. *Secretion per vesicam.*

27. We have now to examine how far the secretions present us with measures of the work performed by the body. Commencing as we did in the first division of the lecture, it is necessary to inquire how far the urea secreted by a man living on a mere subsistence diet, represents the amount of tissue which we have supposed to be wasted in internal dynamical work. Further on it will be seen that, in a man of good digestion at least, one-twelfth of the nitrogen of the food passes away in the fæces, without having been built into muscle or other tissue. Hence, of the 875 grains (2 oz.) of flesh-formers required to support *opus vitale*, 73 grains will pass out *per anum*, and 802 grains will be moulded into tissue, and be transformed into urea and the other products of wasted muscle. Hence, in the urine of a man supported by the lowest diet sufficient for life, we should still find 267 grains of urea. The same amount must appear in the first days of starvation, during which life is supported by the wasting tissues; or what is the same thing, it will appear when non-nitrogenous food is taken. In Ranke's experiments upon himself, we find that, in the first case, he passed 17·02 grammes of urea, and in the second case, 17·10 grammes.[1] The mean gives 263 grains of urea, a number remarkably close to our calculated quantity, and probably identical, if the undetermined uric acid be accounted for. Beigel[2] during

[1] Müller's Archiv. 1862, S. 358.
[2] Nov. Acta. Acad. Nat. Curios. xxv.

a three weeks' "hungercur," found the urea sink to 17·83 grammes, or 275 grains. A patient in the fifth week of typhus would possibly pass even less than 267 grains of urea, because part of the subsistence food, in the low state of dynamical vital work, would go to build up tissue; and accordingly we are not surprised to find that Brattler,[1] in the fifth week, found the urea as low as 16 grammes (247 grains). But when the patient becomes convalescent, and receives the standard diet for quietude, viz., 2·5 ounce of flesh-formers, he should then pass 335 grains of urea. Turning to the researches of Vogel[2] and of S. Moos,[3] we find that the secretion gradually rises from 22 grammes (339 grains) to the normal quantity of 35 grammes. Haughton[4] also states that convalescents in hospitals pass about 300 grains of urea.

28. The experiments of the latter observer on the amount of urea secreted by average healthy men, living on a mixed diet, give from 560 to 580 grains. The mean of the extensive table of analyses in Parkes'[5] excellent work is, however, only 512 grains. If we add to this his average for uric acid, in its equivalent of urea, we would have 521 grains. If now we take as a mean, for the present, the results of Barral,[6] Valentin,[7] Vierordt,[8] and E. Smith,[9] for the nitrogen in the fæces as being about one-eighth that in the urine (one-twelfth, according to Ranke), then this, calculated as urea, would

[1] Ein Beitrag zur Urologie, 1858, p. 19.
[2] Zeitschr. f. rat. Med. iv. p. 362, *et seq.*
[3] *Idem.* vii. p. 291.
[4] Urine of Healthy Men, p. 30.
[5] Parkes on Urine, p. 15.
[6] Comptes Rend. xxvii. 361. Ann. de Ch. et Phys. [3], xxv. 129, 171.
[7] Text-Book of Phys. 326.
[8] Vierordt, Phys. 192.
[9] Phil. Trans. v. 151, p. 747, *et seq.*

give $521 + 65 = 586$ grains of an equivalent of urea. We can convert this into flesh-formers :—

$$586 \times 3 = 1758.$$

Now 4 oz., or 1750 grains, form the usual diet of non-labouring men.

It will thus be seen that numbers closely approximating to the demand are obtained from recognised averages. But in order to apply them to the special class of healthy men (soldiers) described in Table II., we must take the diet as there given. Soldiers during peace are supposed to be well exercised by a daily march of seven miles. This march represents work equal to 38,333 metre kilos. If we take Haughton's mean of 575 grains of urea for such men, then the tissue transformed to produce this would be 3·94 oz., to which, using Ranke's proportion of one-twelfth of nitrogen in fæces, as we do for reasons hereafter to be stated, 0·33 oz. have to be added ; making 4·27 oz. as against 4·21 oz. in Table I. Taking, then, 3·94 oz., we have :—

Potential energy in transformed tissue,	211,822 metre kilos.
Useful external work, . . .	38,333 „

But as the former number includes the energy required to support *opus vitale*, we obtain the amount available for external dynamical work by subtracting it :—

$$211{,}822 - 107{,}524 = 104{,}298 \text{ metre kilos.}$$

Hence we have still nearly three times as much force available as is represented by useful work ; but we need not be surprised at this, when we know that the healthy soldier is capable of more exertion than he takes in peace.

29. Passing from our standard man in health to a hard-worked labourer, we can readily calculate how much urea should be produced by his plastic food. We obtain the amount which is transformed from tissue by deducting that which passes away as fæces :—

$$2406 - \frac{2406}{12} = 2205{\cdot}5 \text{ grains.}$$

Without any error worth taking into account, the urea may be obtained by dividing this number by 3 (the correct number is 3·01) ; hence the working man, doing really a hard day's labour, should have 735 grains of urea in his urine, including its equivalent of uric acid. There are very few estimates of the urine of hard-worked labourers, and I have found it no easy matter to induce them to be made the subject of experiment. Nevertheless, in conjunction with my friend Dr. A. Dalzell, I have estimated the amount of urea in the urine of hard-worked labourers, and we are still continuing our inquiries on this subject. Before alluding to them, it will be more convenient to consider Dr. E. Smith's[1] researches on weavers and tailors. The two weavers were engaged in "the very laborious occupation of wide-width cocoa-matting." Applying my tables to the recorded food of these men, I find that they received a daily supply of 5·33 oz., or 2333 grains of plastic nutriment, containing 366 grains of nitrogen. As an average of twenty-six days' experiment they gave :—

702·9 grains of urea, containing .	328·0 grs. nitrog.
8·52 oz. fæces, containing . .	40·93 ,, ,,
Total nitrogen, . .	368·93 ,, ,,

As this differs by only three grains from the nitrogen ot

[1] Phil. Trans., v. 151, p. 747, *et seq.*

the ingesta, as determined independently of the experiment, the latter has obviously been done with great care.

The tailors, who were fully fed, received 4·63 oz. flesh-formers, according to my tables, containing 318 grains of nitrogen, and as an average of twenty-six days gave in egesta :—

608·4 grains of urea, containing .	283·7	grs.	nitrog.
6·98 oz. of fæces, containing .	27·43	„	„
Total nitrogen, . .	311·13	„	„

These tailors were however overfed, for while the weavers slightly lost weight, the tailors gained about 16 oz. each during the experiment. The lesser quantity of urea in this case was a necessary result of diminished food and work as compared with the weavers.

A distinguished colleague in my University, Professor Christison, whose knowledge as a chemist does not require to be referred to, had long since the idea that work, with corresponding food, increased the urea. When he was twenty-eight years of age and remarkably vigorous, he worked for two days as a carpenter to try this problem, and in addition walked on each of these two days ten miles, at a pace of nearly five miles per hour. As a mean of the two days, he passed 845 grains of urea, but as the process of analysis was not then by the mercury method, we may reduce it to make it comparable to our present standard, to 800 grains. But perhaps this may be too large a deduction, as we find that Hammond, exercising himself in a similar hard way, passed 865 grains.

We may compare these instances with those recently determined in my laboratory, and which were generally

made on two men in each occupation for at least two days :—

Hammerman, ...	530 grains.
Quarrymen, ...	550 „
Tailors, ...	608 „
Weavers, ...	703 „
Blacksmiths, ...	695 „
Forgemen, ...	740 „
Hard-working—pedestrian, .	800 „

The work of the two first set of workmen is fatiguing, but not laborious. The work of a hammerer (9) is 480,000 foot-pounds, which is within the capability of a fairly fed man with 4·2 oz. of plastic food. The difficulty of getting working men to understand the value of such inquiries has considerably retarded these determinations. In the case of the two blacksmiths, the difference between the urea of Sunday and labouring days is instructive :

	Sundays.	Labour Days.
H. 1.	38·56 grammes.	1. 41·38 grammes.
H. 2.	34·47 „	2. 46·69 „
Mean,	36·51	44·03
M. 1.	31·42 grammes.	1. 40·61 grammes.
M. 2.	31·06 „	2. 49·08 „
Mean,	31·24	44·84

H. on the Saturday evening previous to the first Sunday had killed a pig and made merry with his friends, having, in fact, been drunk ; hence that day's urine was probably deranged. Taking the mean then of the three observations, we have for

	Grammes.	Grains.
Sundays, or days of rest, . .	32·32	499
Week-days, or days of labour, .	44·43	686

The difference between 686 and 695, as given in the table, is for the equivalent of uric acid.

30. It will be seen that the demand of 730 grains of urea for a man doing the hard work of 790,000 foot-pounds is not beyond what is found in many cases. In fact, it follows as a necessity, if Tables III., IV., and V. are correct returns of the food of men engaged in labour. The researches of Lehmann[1] and Ranke[2] have shown, that when much nitrogenous food is taken, an increase in the amount of urea follows. If, then, the plastic food of the adult man stands to the hard-worked labourer as 4·2 : 5·5, the urea must increase in nearly like proportion. There is now no longer any question that all the nitrogen of the ingesta is to be found again in the urine and fæces. Bischof and Voit[3] have proved this for dogs; Henneberg[4] for cows; Voit[5] for dogs and pigeons; Lehmann[6] for pigs; Ranke[7] and Smith[8] for men. As this is now determined beyond doubt, it scarcely needed new experiments to prove that a labourer, eating more food than a man not working, must pass more urea than the latter. The dispute as to the effects of *luxus consumption* involved the decision of this as the common battle-field for the disputants on both sides. Thus Beigil[9] found a secretion of 711 grains of urea in the case of men, when they had lived on animal food and rested, and 806 grains, under the same conditions, when they had active work. Becher found 729 grains,

[1] Phys. Chem. ii. p. 450.
[2] Ranke, Müller's Archiv. 1862.
[3] Ernährung des Fleischfressers, 1860.
[4] Quoted by Voit, *infra*.
[5] Stickstoff-Kreislauf. Ann. der Ch. und Phar. 1863; Supp. Bd. 238.
[6] Zoochemie.
[7] *Op. cit.*
[8] Phil. Trans. 1862.
[9] Day's Phys. Chem. p. 43.

Lehmann 798 grains, and Ranke 1330 grains under like conditions. We need not therefore discuss the *questio vexata* as to whether albumen may or may not pass directly into urea, when in excess in the blood, without being built into tissue, for this is not the normal mode of nutrition. *Luxus consumption* may be a question to discuss when considering aldermanic dinners, but it can have no meaning when applied to the hard fare of the artisan, who takes no more food than is necessary for his work. The discussion also as to whether exercise increases the elimination of urea has little further interest for us, when we find such men as Lehmann,[1] Hammond,[2] Beigil,[3] Speck,[4] Franque,[5] and Benecke,[6] deciding in favour of the fact that it is increased, against the varying experiments of Voit[7] and the younger Draper[8] on the other side. Dr. E. Smith has explained many of the anomalies of the latter physiologists, by showing that the period of the production of urea is not necessarily its period of elimination.[9] In most of the experiments made on this subject, the heavy exercise has been taken, not with the corresponding diet, but with the old diet ; and under such circumstances, the increased elimination

1 Phys. Chem. Bd. ii. 449.
2 Amer. Journ. Med. Soc. 1855 and 1856.
3 Ueber die Harn, etc. S. 42.
4 Archiv. des Vereins für Wiss. Heilk. Bd. iv. 484, and Bd. vi. 161.
5 Schmidt's Jahrbuch, 1856.
6 Nord, Sec Bad. 1855, p. 83.
7 Unters. über den Einfluss der Muskelbewegung, etc., 148, *et. seq.*
8 New York Jour. Med. 1856.
9 The experiments of E. Smith upon prisoners working on the tread-mill are perhaps the most difficult to explain, for with this heavy work there was only an increase of 16 grains daily. They worked for one-third the time, but clearly under abnormal conditions, for "their muscular system was overworked and underfed." Their food I find contained daily 250 grains of nitrogen, while their urine and fæces contained 280 grains. Hence the working experiment was not one of health. The probable explanation lies in Smith's own words : "The reparation is in excess during the periods of rest, and restores the equilibrium on a long average."

of urea from the system is sometimes retarded two days. Hammond's experiments, even upon the same diet, were however very conclusive. His results are as follow :—

	Urea.	Uric Acid.
With no exercise, .	487·0 grs.	24·9 grs.
Moderate „ .	682 1 „	13·7 „
Hard „ .	865·0 „	8·2 „

31. When a large amount of animal diet is the chief source of food, exercise becomes a necessity, in order to waste the tissues for the support of respiration and other vital movements. Without it the animal soon loathes the food. This is not only the experience of carnivora, but also of man. Darwin tells us that, when in the Pampas, he lived tolerably well on a meat diet, "but felt that it would only agree with me with hard exercise;" and he tells us that the Guachos, who live upon meat, eat largely of fat, probably not only for respiratory food, but also as a protection against unnecessary muscular waste, as we have explained. Sir John Richardson observed the same fact in his Arctic travels, having noticed "that when people have fed a long time solely upon lean animal food, the desire for fat becomes so insatiable that they can consume a large quantity of unmixed, and even only fat, without nausea." The hyena in confinement wastes its tissues by moving backwards and forwards incessantly in its den, and thus is able to consume its animal diet. All this shows that the normal function of nutrition is to build in plastic food into tissues, to be transformed by internal and external dynamical work into carbonic acid, water, and urea.

32. We have confined our attention chiefly to urea, because, as a representative of dynamical labour, it is

not mixed up with any other kind of work, such as *opus calorificum.* Carbonic acid is a marked product of work, but then it represents the sum of two factors,—increase in dynamical and in respiratory action. Thus a labourer, living upon our standard diet, exhales in eighteen hours' quietude, and six hours' hard work, the following quantities of carbon, in the form of carbonic acid, after deducting the carbon in urea and in fæces:[1]—

In 18 hours' quietude, 2375 grs. of carbon.
6 „ labour, 3212 „ „

In one hour's work, 535 grains of carbon are exhaled as carbonic acid, of which nearly one-fourth, or 135 grains, is due to the transformation of tissue, and the rest to the increased demand of the oxygen inspired for non-nitrogenous food.

B. *Assimilative Work, as Measured by the Secretions per Anum.*

33. The measure of the digestive or assimilative work, in a man of healthy digestion, is, I believe, to be found in the nitrogen of the fæces.[2] Although the alvine evacuation frequently does contain undigested food, either in cases of over-eating or of indigestion, in full health it is difficult to find with the microscope even traces of unchanged food. Bischof and Voit could not detect any muscular fibres in the fæces of their dog; and not even

[1] 220 grains of carbon are allowed for fæces, all of which is deducted from the six hours' labour.

[2] It is only as this lecture passes through the press that I observe Marcet has given the same view, without however working it out. Not having found any such views in his two papers on fæces, I did not think of looking at his lecture on the chemistry of digestion till the last moment. The passage to which I refer is as follows:—"The principal object of the alvine evacuation is obviously to rid the body of certain parts of the intestinal secretions, which, after having served their purpose in effecting the digestion of food, are not fit to return to the blood."—Jour. Ch. Soc. xv. 418.

fat, when that had been purposely added to the meat. Rawitz[1] and other observers are of the same opinion. Hence the common notion that fæces represent the refuse of food is not supported by correct observation. Undoubtedly they contain various ingredients, nitrogenous as well as non-nitrogenous, mixed with mineral matter (Marcet).[2]

34. The average weight of fæces secreted in health is 4·6 oz., according to Wehsarg,[3] or 5½ oz. (Liebig). In Ranke's[4] experiments, on a mixed diet, the nitrogen excreted by the fæces is to that in the urine as 1 : 12·5. We take one-twelfth as the amount in health. But although this is the case in man, it is not so with regard to the carnivora. In Pettenkoffer's experiments with a flesh-fed dog, the nitrogen in the fæces was to that in the urine as 1 : 72 ; and in the still more extensive experiments of Bischof and Voit, as 1 : 76. But the ratio[5] alters when fat or starch is added to the flesh ; in the first case it is as 1 : 41, and in the second 1 : 40. When the dog was fed on flesh and sugar, it was as 1 : 23·3, and on starch alone the proportion became reversed, and then the nitrogen in the fæces was to that in the urine as 2 : 1. A little consideration will explain these differences. There are four fluids engaged in the promotion of digestion. All of them contain albuminous fer-

[1] Ueber die Einfach Nährung Mittel.
[2] Phil. Trans. 1854 and 1857.
[3] Mikros. Und. Chem. Untersuchg. des Fæces, 1853.
[4] *Op. Cit.* p. 311.
[5] These numbers are relative, not absolute. The fæces of flesh diet contained 6·5, of starch 4·4, of sugar 7·9 per cent. of nitrogen ; but the proportions of nitrogen in urine to nitrogen in fæces are as given in the text. Thus we find, on summing up the quantities, that the nitrogen in urine and in fæces, on a diet of flesh and sugar, is, in grammes, as 85·22 : 3·65 ; on flesh, starch, and fat as 101·46 : 2·57 ; and on starch alone as 5·68 : 10·26. I have omitted the fæces on bread diet, for they seem to have been chiefly undigested bread.—(Ernährung des Fleischfressers.)

ments, which receive special names, as pepsin when in gastric juice, ptyalin when in saliva, pancreatine in pancreatic juice, and intestinal ferment in the juice of the intestines. But we know nothing more of their chemical composition than that they are albuminous bodies, slightly oxygenized, and in the process of change. We do know that they have different actions,—pepsin acting on albuminous bodies, ptyalin and pancreatine converting starch into sugar, and the latter fat into its acids and glycerine ; but in all probability the same ferments in different conditions produce their varying effects, just as we find the gastric ferment also able to act upon fats as well as on flesh-formers,[1] and the intestinal ferment combining the functions of the salivary, gastric, and pancreatic ferments. In fact, experiment tells us that alkaline gastric juice acts like pancreatic juice, and the latter, when acidified, plays the part of the former.

Referring to the proportion of nitrogen in the urine to that in the fæces of the carnivora, it is now possible to explain the apparent anomaly, that the addition of non-nitrogenous aliments to the diet, increased, instead of diminishing, the amount of that element in the fæces. When the animal is fed on flesh free from fat, the gastric ferment alone is brought into activity, aided partially perhaps by the intestinal ferment, and the residue of these appear in the fæces, which are found to contain but little nitrogen. When fat is now added to the diet, a large amount of pancreatic juice is brought into activity, and the used-up ferment of this juice is added to that of the gastric and intestinal juices as before. Hence we find that the proportion of nitrogen in the fæces is

[1] Marcet, Chemistry of Digestion, Chem. Soc. Jour. xv.

increased. When starch is mixed with the flesh, then the salivary ferment co-operates with the other three ferments in preparing the food for assimilation, and we find the proportion of nitrogen rather greater than before. When a carnivorous animal is placed in such an anomalous position as in feeding it on starch alone, a much larger quantity of salivary, pancreatic, and intestinal ferments appear to be called into action to digest this unusual and unmixed diet, and hence the amount of nitrogen in the fæces becomes increased to an unusual amount.

35. The usual amount of nitrogen in the fæces of man is 6·5 per cent. in dry, and 1·7 in fresh excrement; while the carbon is from 43 to 44 per cent. in the former. This is almost identical with the composition of normal fæces in the carnivora. The reason obviously is, that the changed albuminous ferments, which form the nitrogenous constituents of fæces in health, are the same in both classes of animals. Just as yeast loses some of its nitrogen by work; as emulsin becomes poorer in nitrogen and richer in oxygen when it has ceased to act on amygdalin, so do these different forms of albumen in their degradation suffer like changes. A well-known experiment of Lehmann is instructive on the subject under consideration. When emulsin (the casein of sweet almonds) is introduced with amygdalin into the stomach of an animal, the well-known fermentation, by which that body is converted into oil of bitter almonds and prussic acid, takes place, and the animal dies. On the other hand, when emulsin alone is introduced to the stomach, and amygdalin is injected to the blood, the animal does not suffer by the experiment. But upon reversing the mode of administration, and injecting the

emulsin to the blood, and putting the amygdalin into the stomach, the animal dies as before. Hence we find that the ferment, after acting upon the substances which it met with in the intestines, could not be absorbed ; for had it been, it would have met with amygdalin in the blood, and would have produced fatal effects. That it had acted as a ferment upon the materials in process of digestion, and had become exhausted, is certain, for it altogether changed in its passage, the fæces of the animal not containing any emulsin capable of acting upon fresh portions of amygdalin. No experiment could be more conclusive for our views, because emulsin is simply changed casein, as these digestive ferments are changed albumen, each having certain peculiarities of action, according to the alkaline or acid fluids with which they act, or with other varying conditions.

36. Let us now return to the proportion of nitrogen found in the alvine dejections of man ; it stands in relation to that in the urine as 1 : 12. Where it is present in larger proportions than this, then the excess is probably due to undigested flesh, or to an excessive secretion of ferments necessary to overcome some digestive difficulty. In other words, one-twelfth of all the plastic food taken by a man is converted into digestive ferments, and then is excreted *per anum.*

I am not inclined to agree with those physiologists[1] who consider that these ferments secreted from the blood are the degraded products of tissue-waste in their passage to urea. On the contrary, I believe them merely to be albumen of the blood, the oxygenation of which is incipient, so as to make it ready to build up tissue, as in

[1] Draper's Human Physiology, p. 84.

its passage to fibrin.[1] Hence, when there is an extensive demand on the blood for tissue-material, as in the case of work in excess of the food supplied (for instance, as observed by E. Smith with his overworked prisoners), then the amount of the alvine dejection diminishes. These digestive ferments secreted from the blood cannot be albuminous materials in a downward career, otherwise their surplus, beyond that required for fermentation, would not again be absorbed into the nutrient fluid. It is only a small portion of the whole that is rendered unfit for re-absorption and is reduced to a degraded condition. If the great bulk of what is generally esteemed to be the ferments were not taken back into the blood, the amount of nitrogenous matter in the alvine dejections must be much greater than we find to be the case. Let us take very moderate computations as to the quantities of digestive juices secreted in twenty-four hours by a standard man, and this re-absorption will appear to be a necessity—

1·6	kilog. of	saliva[2]	contains	2·4 grammes	ptyaline.
6·4	„	gastric juice[3]	„	20·5 „	pepsin.
4·0	„	pancreatic[4]	„	50·8 „	pancreatin.
0·2	„	intestinal[5]	„	1·8 „	ferment.
			Total,	75·5 grammes.	

Now as the whole fæces contain only 9·4 grammes of these exhausted ferments, it is obvious enough, that the

[1] Smee, R. S. Proc. xii. 399, 505.

[2] Dalton's Human Phys. p. 96.

[3] Katherine Kutt, the Esthonian peasant, with a gastric fistula, gave no less than 30 lbs. daily; the usual estimate, however, from researches on dogs, and applying them to man, is 14 lbs.

[4] The estimates on this subject vary enormously, some going as high as 15 lbs. for a standard man. I have therefore taken a low estimate, nearly that of Bernard, who has devoted so much study to the pancreas.

[5] I allow this for intestinal juice, from the experiments of Bidder and Schmidt. Probably all the estimates are 25 per cent. too low.

larger quantity represented above cannot consist of degraded matter in its descending career. When it is further borne in mind that the daily waste of tissues in a healthy man is only 112 grammes, it is impossible for us to suppose that more than half that quantity of degraded matter is preserved in the blood, to be excreted and then re-absorbed. This view would be quite inconsistent with the admirable arrangements of the excretory organs for speedily carrying off used-up matter from the nutrient fluid.

The functions of these digestive secretions must be considered as assimilative, in the largest sense of the term. Chemical affinity generally is assimilative effort. When hydrogen unites with oxygen, each element endeavours to assimilate the chemical characters of the other element to itself, and when they are equal in power neutrality results. These ferments, as they are termed, when secreted in the digestive fluids, are albuminous substances changed and fitted for assimilation in the body, and capable of preparing the ingested food to assume their own state. They meet with resistance, which their large mass enables them to overcome, but a small portion of them succumb in the conflict, and are finally excreted in the alvine dejections, along with certain non-nitrogenous materials which have probably been used in co-operation with them to fit the calorifacient constituents of food for absorption into the blood.